Solar Powered AUVs; Sampling Systems for the 21st Century

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LONG TERM GOALS

The long-term goal of this program is to investigate those technologies that will enable the use of solar energy to power Autonomous Underwater Vehicles (AUVs). The program is focused on investigation of our ability to extract sufficient energy from the sun's radiation to power an AUV and our ability to efficiently manage the collection, storage, and utilization of that energy such that an AUV is able to perform tasks required during a mission. It is expected that, at the conclusion of this phase of the program, we will understand not only the relevant technologies, but also the advantages, methods of implementation, and limitations of their use on solar AUVs.

OBJECTIVES

The objectives focus on investigations directed at better understanding the characteristics and limitations of the solar energy system components, specifically the photovoltaic array, the charging system, the energy storage system, the power management aspects, and the unique constraints imposed on those systems. Our efforts were also focused on conducting experimental tests and evaluation of subsystem components to acquire empirical data for assessing subsystem performance. Both laboratory and in-water testing were, and are, being conducted to (1) assess the performance of a solar energy system, (2) investigate and assess various energy management strategies, (3) investigate effects of biofouling on solar panel efficiency, and (4) investigate the extent to which sea wave action and water splashing across a solar panel reduces energy collection efficiency. We are also investigating means of remotely communicating with the solar powered AUV on a regular basis. In parallel with these activities, IMTP in conjunction with AUSI staff, have fabricated a prototype solar powered AUV testbed for the purpose of evaluating basic concepts developed under this program.

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APPROACH

Conduct research of existing solar energy components, their usefulness and potential for application in an integrated system for AUVs. Conduct experiments to acquire data and assess the extent to which solar energy is viable as a power source for AUVs. This involves designing a solar energy system testbed to conduct laboratory experiments to specifically determine the efficiencies and limitations of subsystems composed of PV solar arrays, battery systems, charge monitors and charge controllers, etc., and to assess the degree of integration compatibility between the various electronic components. Use the solar energy testbed to investigate various power management strategies developed within this program. Design and fabricate a solar AUV platform for the purpose of carrying out in-water evaluations of energy collection under conditions of wave motion and water splashing over solar arrays. Conduct in-water tests of at least two types of solar array panels to determine relationship between biofouling degradation of solar panels and elapsed time while under water at shallow depth. Develop software models of waves, platform, and energy system to serve as an evaluation and design tool and to conduct simulation experiments of various aspects of solar AUV systems. Design and fabricate a simple solar AUV prototype vehicle to conduct at sea tests of the first principles of solar powered AUVs.

WORK COMPLETED

Biofouling. Experiments were conducted to investigate the effects of biofouling on solar array panel energy collection efficiency. Data was acquired under worst case conditions with the solar arrays just below the sea surface, in a calm port region fully exposed to the sun all day long. The results of this effort have been published [1] and are described briefly in the results section below.

Sea and Wave Effects. At-sea experiments were also conducted with a prototype Solar AUV body developed under this program to determine the effects of wave motion and water washing over the panel on solar array energy collection efficiency. These results have also been published [1] and are described below.

Modeling. Physical parameters of the solar AUV body were entered for 18 stations along the body centerline axis in the Navy Standard Ship Motion Program (SMP). The model provided output motion (pitch and roll) data for the vehicle on the surface of the ocean under varying sea state conditions. Some preliminary results have been published [2]. The data from the sea and wave experiments is being used to correlate the solar collection efficiency into the model's output under varying sea states.

Solar Energy System Testbed. A solar energy testbed has been designed and fabricated. This system consists of all the elements of a solar AUV energy system such that experiments can be accomplished to make empirical measurements of a solar AUV energy system under operating conditions. Experiments are being conducted to determine energy acquisition efficiencies from solar arrays using varying types of circuitry, battery and power management strategies, temperature effects on energy use efficiency, and the efficient utilization of energy by an AUV.

Solar AUV Prototype. A complete solar AUV prototype has also been fabricated. It has been undergoing engineering tests at sea. Most of the experimental effort is on assessing the vehicle's

dynamic behavior and tuning of the control system parameters. Remote communication and GPS updates have also been implemented on the system.

RESULTS

Biofouling Experiments. Two commercially available solar array panels were used in these experiments (May 23 - June 29). The solar arrays were submerged about 1 foot below the sea surface at low tide such that they were exposed to the sun all day. Tests were conducted in the harbor at the US Coast Guard Station at Newcastle NH. The solar array panels' physical layering is shown in Figure 1. Dr. Edwin Grosholz (UNH Zoology Dept.) performed the analysis of biofouling organisms. Figure 2 is a plot of time in days versus solar array panel area fouling and output power for both panels.

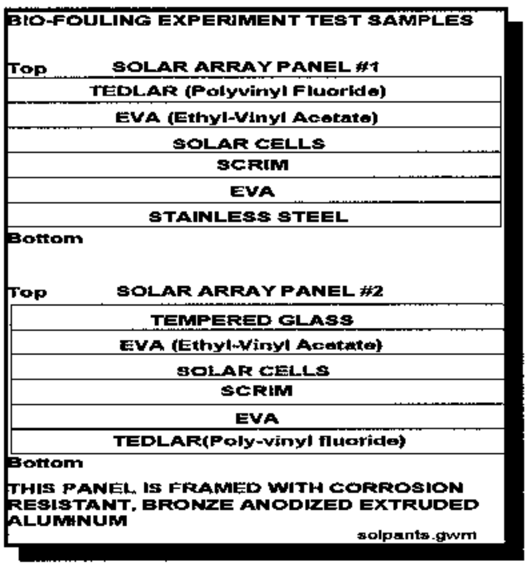

Figure 1: Solar Array Physical Layering: Panel #1 = Lite; Panel #2 = Standard

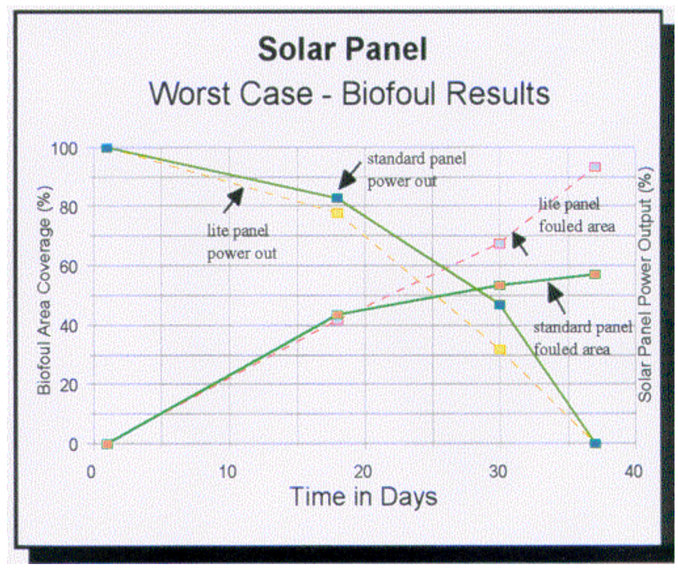

Figure 2: Solar Panel Bio-fouled Area and Power Output versus Time

After the first 18 days, the biofoul area coverage was about 42% and the power output for both panels remained at about 80%. After 30 days, the "standard" panel fouled area was 53% and its power out put was down to 47% while the "lite" panel fouled area was at 67% with a 32% power output. The standard panel seems to resist fouling better than the lite panel and both systems provided 80% power output after 18 days under these extreme conditions. A solar array panel mounted on an AUV will likely take a longer period to foul since it will be subjected to constant water washing over its surface and will be making regular excursions into deeper water.

Sea and Wave effects. These experiments were designed to measure the decrease in solar energy acquisition due to (1) seawater washing over the solar panels and (2) wave motion effects on the solar array angle in varying sea states. A Solar AUV body was designed and fabricated to have the same surface motion characteristics as the prototype solar AUV. The system included a Solarex MSX30L solar array, a microprocessor, a gas gauge and charge controller (BQ2112 - Benchmarq), and a NiCad battery system. A duplicate system was housed in a land station on shore that also monitored weather data. Data was gathered by both systems simultaneously while the solar AUV body was at sea about 3 - 4 miles off Portsmouth NH, where the land station was located. Figure 3 is a plot of the results of these experiments. Thus far, we have acquired data up to Sea State 3 and plan to get data for Sea State 4 and 5. In general, the solar AUV body floats very quietly in the wave surface and is almost constantly awash. The data is a plot of percentage difference in energy acquired between the two systems (sea and land). A positive value in the Y-axis indicates that the sea system acquired more energy than the land system while a negative value indicates the opposite. There are two curves in this plot. The top curve represents the actual raw energy acquired while the lower curve includes temperature correction. This temperature correction is used in order that the results measure only the effects of the wave and water interaction with the solar collection system. The correction takes into account three different effects of temperature on charge acquisition: (1) gas gauge compensation factor, (2) battery self-discharge compensation factor, and (3) solar array temperature effects. Without temperature correction, the at-sea system collected more energy than the land system at least up to Sea State 3. The temperature corrected data indicates that the at-sea system collects slightly more energy than the land system up to about Sea State 1, however, as the sea state increases the land system begins to acquire more energy than the sea system and is about 20 % more at Sea State 3. The results of these tests will be incorporated into the solar system models, which will be used for predicting energy acquisition under varying sea state conditions.

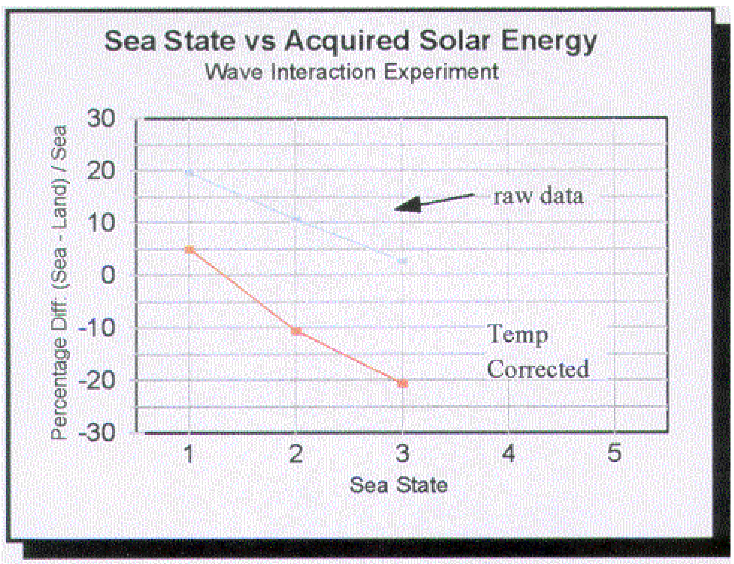

Figure 3. Solar AUV Wave & Water Interaction Data

A prototype solar powered AUV has been designed, fabricated and has been undergoing at-sea testing. The system has dimensions of 1.8, 0.73, and 0.31 meters and a working depth of 1000 meters. A detailed description of the vehicle and its hydrostatic, hydrodynamic, energy, and sensor systems can be found in [3]. At-sea testing shows that the vehicle's hydrodynamic characteristics are very similar to that predicted by both calculation and in the wind tunnel tests carried out at the beginning of the project. Experiments thus far indicate that either the drag resistance is higher or the propeller efficiency is lower than predicted resulting in more energy use than expected. This is being investigated at present.

While moving on the surface, the flap has to be offset about 5 degrees to prevent the vehicle from diving due to the downward slanted shape of the vehicle bow. Pitch and roll angles on the surface are relatively small and about the same as the wave angles. There is no high frequency rolling as the system was designed to damp oscillations.

The GPS system works in calm seas but the antenna will have to be elevated as it is presently only 5 cm above the deck and is often awash due to wave action. It is preferable to attach it to a moving telescopic or moveable rod to minimize drag while operating below the surface. The RF modem's antenna currently in use behaves similarly and will also be moved higher.

IMPACT/IMPLICATIONS

The use of solar powered AUVs in the future will allow scientists and military investigators to perform missions of the sort, which are unattainable at present. Solar AUVs will allow users to remotely conduct missions in which they can acquire significant data over vast areas of the ocean for long periods of time, and have access to the data and vehicle through communication on a daily basis. This is a significant first step in providing at sea satellites.

TRANSITIONS

This technology should undergo a series of long endurance at sea trials in conjunction with scientists and/or military users to assist in the transition from technology development and assessment to commercial viability.

RELATED PROJECTS

This work has direct relevance to the Autonomous Ocean Sampling Network (AOSN) project since solar powered AUVs could well serve as autonomous agents within that network. Similarly, the work on Cooperative Distributed Problem Solving for controlling AOSNs (ONR #N00014-96-1-5009), which is also being accomplished at AUSI, also is relevant for this solar powered AUV system.

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